Can label priors in global tractography resolve crossing fibre ambiguities?

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TARGET AUDIENCE – The diffusion tractography community.

PURPOSE – Conventional tractography suffers from ambiguous local fibre configurations, due to partial voluming and the symmetry of DWI data[1,2]. It is, for example, not possible to discriminate between crossing and kissing fibre bundles (Fig. 1) or between bending and fanning configurations. Global tractography methods can be more robust against this problem by directly optimizing the fibre density in the entire image[2–4]. Here, we impose an atlas prior on the shape of labelled fibre bundles in global track reconstruction, and hypothesize that it will reduce false positive fibres.

METHODS – *Global tractography:* The tracks in the global tractography framework[4] are modeled by chains of segments, that each have a fixed and equal contribution to the simulated data. The optimization, which strives for maximal similarity to the measured data subject to smoothness and connectivity priors, relies on a Markov Chain Monte Carlo technique that generates random proposals for creating, deleting, and moving segments and for (dis)connecting neighbouring segments. *Label Prior:* We introduce a white matter atlas that provides, at every position **x**, the probability $p(L_\mathbf{x} = l)$ of a bundle label $L_\mathbf{x}$[5,6]. Naturally, $\sum_l p(L_\mathbf{x} = l) = 1$. The label probability of a track *t* is then defined as

$$p(L_t = l) = \frac{1}{Z} \prod_{\mathbf{x} \in t} p(L_\mathbf{x} = l) \quad ,$$

where *Z* is the normalization across all labels *l*. As such, a track connecting two disjoint label regions has probability 0, while a track that runs through a single bundle region will have probability 1 for that label. In practice, bundle label maps will overlap in crossings and due to atlas uncertainty and the attributed track probabilities will not be binary. The (dis)connect and move proposals in the global tractography method are then adapted to incorporate this prior label probability.

RESULTS – *In silico phantom:* The Phantomas software[7] was used to generate data with known ground truth fibre bundles. The data is sampled at the HCP gradient scheme (see below), at signal-to-noise ratio 30. The label probability atlas is based on the ground truth fibre bundles, using uniform probability in "empty" regions. Fig. 2 shows the reconstructed tracks, coloured by their maximum likelihood label. We compare the Tractometer metrics of this result to those without the prior in Table 1. In both cases, all 27 valid bundles (VB) are found; the number of invalid bundles (IB) is strongly reduced. With the prior, invalid connections (IC) are suppressed in favour of valid connections (VC) and at the cost of slightly improved no connections (NC). *In vivo data:* Data of a single subject were provided by the NIH Human Connectome Project, WU-Minn Consortium[8]: 18 gradients at b=0s/mm^2, 3 x 90 gradients at b=1000s/mm^2, 2000s/mm^2, and 3000s/mm^2, 1.25mm isotropic voxel size. A manually segmented DTI tractography atlas[9] was used for creating the label probability maps (22 labels in total), normalizing all label probabilities and using a uniform prior in unlabelled regions, and registered to subject-space with FSL FNIRT. The output tracks with label probability above 95% are shown in Fig. 3 for 5 bundles in the cerebrum. The forceps major substructure was segmented via an inclusion ROI in the mid-sagittal plane on reconstructions with and without label prior (Fig. 4). Imposing the prior reduces false positive fibres.

DISCUSSION – The results on the in silico phantom demonstrate that imposing a "perfect" label prior effectively suppresses false positive connections. The few invalid connections that do occur either run through the "grey matter" area (uniform prior), or were misclassified due to edge effects at the end ROI boundaries. In real data, the situation is more difficult for two main reasons. First of all, the atlas is inherently incomplete, i.e., not all structures are (and may never be) labelled, and its DTI-based nature does not account for crossing fibres. Secondly, registration artefacts affect the labelling at the edges between neighbouring bundles, say the corpus callosum and the fornix. Nevertheless, most large white matter bundles can be segmented and spurious fibres are reduced. Future work should first of all focus on building a more detailed atlas. Multi-atlas techniques may help to alleviate registration effects.

CONCLUSION – We introduced a label prior in global tractography, which allows direct, probabilistic segmentation of white matter bundles. We have shown that this prior improves the track reconstruction, by reducing the amount of false positive fibres.

REFERENCES – **1.** Jbabdi and Johansen-Berg, *Brain Connectivity 1(3):169–183* (2011); **2.** Mangin et al., *NeuroImage 80:290–296* (2013); **3.** Reisert et al., *NeuroImage 54(2):955–962* (2011); **4.** Christiaens et al., *ISMRM 22:270 (2014)*; **5.** Ziyan et al., *Int J Comput Vis 85(3):279–290* (2009); **6.** Yendiki et al., *FNINF 5(23)* (2011); **7.** Caruyer et al., *ISMRM 22:2666* (2014); **8.** Van Essen et al., *NeuroImage 80: 62–79* (2013); **9.** Catani and Thibaut de Schotten, *Cortex 44:1105–1132* (2008).

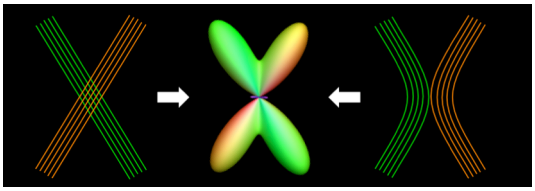

Fig. 1: Illustration of the local ambiguity in DWI data.

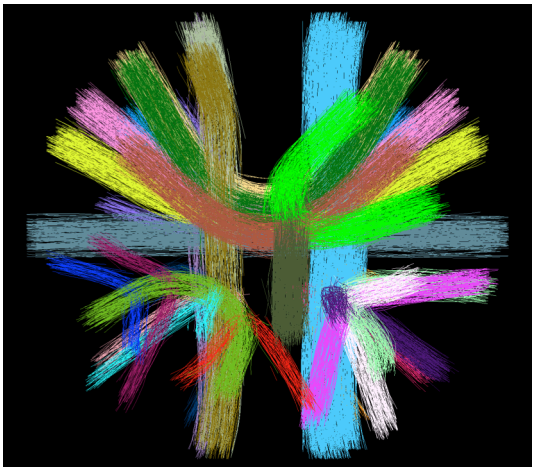

Fig. 2: Labelled track reconstruction on the Phantomas data.

Table 1: Tractometer metrics

	VC	IC	NC	VB	IB
no prior	15.9%	6.9%	77.1%	27	56
prior	19.2%	0.2%	80.6%	27	9

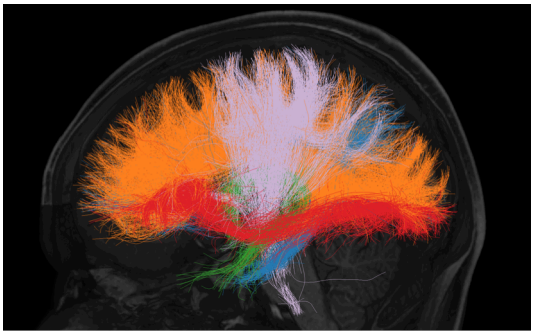

Fig. 3: Labelled tracks with probability p > 0.95: corpus callosum (*orange*), cingulum (*blue*), fornix (*green*), inferior fronto-occipital fasciculus (*red*) and corona radiata (*violet*).

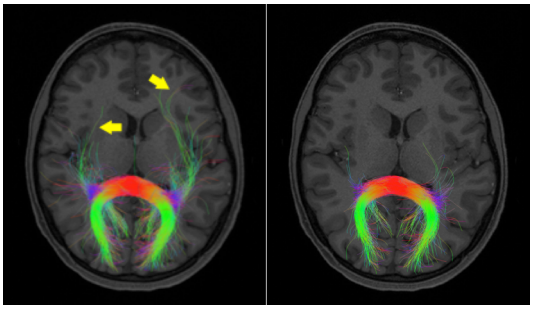

Fig. 4: Segmentation of the forceps major without label prior (*left*) and with label prior, p > 95% corpus callosum (*right*).